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ABSTRACT

The research reported in this paper investigated the effectiveness of an instructional strategy, ideational confrontation, in producing conceptual change. Participants of the study were a group of middle school students (N=13) who were designated as academically gifted and a group of non-physics major university science graduates (N=6) who were studying to become secondary science teachers. Assessments were made of all students' cognitive structures before and after instruction. Content of instruction varied with the two groups but the ideational confrontation strategy was the same. Data findings are reported and results indicate that the effects of the ideational confrontation strategy differed somewhat for students with different characteristics but the strategy evidenced promise for engendering restructuring of students' existing knowledge and for changing the content of their knowledge. Instructional implications are reviewed. References are provided. (ML)

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EFFECTING CHANGES IN COGNITIVE STRUCTURES AMONG PHYSICS STUDENTS

AUDREY B. CHAMPAGNE, RICHARD F. GUNSTONE, AND LEOPOLD E. KLOPFER

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Learning Research and Development Center
University of Pittsburgh

1986

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Audrey B. Champagne, Richard F. Gunstone, and Leopold E. Klopfer

Children and adults often express quasi-Aristotelian dynamics concepts resembling momentum, acceleration, and the vectorial decomposition of gravitational attraction. Unfortunately, most curricula in physics suggest a purely descriptive (kinematical) investigation of position and time, and provide no means for people to test their own theories of dynamics and to restructure them.

(Easley, 1971, p. 156)

INTRODUCTION

It is now well established that, before receiving formal physics instruction, students possess knowledge which leads them to idiosyncratic interpretations of real world events. Physicists, however, see the same events as exemplifying principles of physics. Because students' interpretations are often at variance with physicists' interpretations, they have been labeled misconceptions, alternative frameworks, personal models of reality, etc. Although forms of such idiosyncratic knowledge have been observed in various content areas, elementary mechanics has been the focus of a number of studies. Our own work has established the common existence of knowledge that is logically antagonistic to the tenets of physics both among students beginning a formal study of mechanics (Champagne, Klopfer, Solomon, & Cahn, 1980; Gunstone, Champagne, & Klopfer, 1981) and among students who have successfully completed an introductory physics course (Champagne, Klopfer, & Anderson, 1980; Gunstone & White, 1981), and we have reviewed the studies that explore the nature of pre-instructional mechanics knowledge and its structural organization (Champagne, Klopfer, & Gunstone, 1982). As the number of studies of pre-instructional knowledge of mechanics has grown, it has become clear that naive schemata students use

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to interpret the motion of objects are extremely resistant to change during formal instruction. As a consequence, there has been considerable interest in attempts to design instruction to facilitate cognitive structure change. In considering this instructional problem, we have previously proposed four dialogue-based instructional strategies specifically designed to alter declarative knowledge about the motion of objects that the students bring to instruction in mechanics (see Chapter 5, this volume). Here, we report on our investigations of the extent to which one of the strategies facilitates change in two quite different groups—middle school students designated as academically gifted and with a demonstrated interest in science in Pittsburgh, and non-physics-major university science graduates studying to become high school science teachers in Victoria—and discuss particular features of the strategy that may be of significance in promoting change. This chapter begins with a brief description of the structure of the instruction and the probes used to gather information about aspects of students' cognitive structures. Some data are then presented and some preliminary conclusions drawn.

INSTRUCTION

The instruction was designed to provide considerable opportunity for students to argue their own interpretations of both specific events and general relationships. It began with a substantial discussion of the question, "What are some of the things we can say about the relationships between force and motion?" and subsequently explored several pertinent topics, including methods of describing motion and force, falling bodies, motion on inclined planes, and forces on objects in a variety of contexts. Demonstrations and direct hands-on experience were used. Group sizes were small and the time spent with each group reasonably long. (Details for each group are given below.) Because of the considerable differences in the two groups, there were necessarily differences in the content of the instruction; however, the basic instructional strategy—ideational confrontation—used with both groups was the same.

Briefly, this strategy first asks the students to be explicit about the notions they use to explain or make predictions about a common physical situation—say, the motion of an air-filled balloon as the air rushes out of it, or the motion of two sleds, one empty and the other loaded, that are released simultaneously at the top of an ice-covered ramp. After a physical situation is described, each student develops an analysis that supports his or her prediction, and then individual students present their analyses to the class. Inevitably, controversies arise, and analyses are modified. Typically, students

with different interpretations begin to attempt to convince others of the validity of their ideas. As a student or group of students defends a position, concepts become better defined, and underlying assumptions are stated explicitly. The net result is that each student is explicitly aware of his or her existing notions about motion that were used in the analysis of the situation of interest. Typically, as a result of these discussions, students become dissatisfied with their current theories.

At this point in the ideational-confrontation strategy, the instructor demonstrates the physical situation (say, he or she lets the air escape from the balloon or lets the two sleds slide down the icy ramp) and presents a theoretical explanation of the results, using the particular science concepts, principles, and theory which the demonstration illustrates. The concepts, principles, and theory in the instructor's scientific explanation usually are different in significant respects from the notions the students used in their analyses. In further discussions, the students compare the elements of their analyses of the situation with the scientific analysis given by the instructor, and identify similarities and differences. This exercise requires the students to confront inconsistencies between their existing notions and the content of the science instruction. The ideational confrontation enables each student to become aware of his or her existing notions and of the need to reconcile them with the science concepts and principles that are to be learned.

PROBES OF COGNITIVE STRUCTURE

Assessments were made of students' cognitive structures before and after the instruction by administering a variety of probes. Detailed discussions of the possible methodologies which could have been employed and why the particular ones were chosen is discussed elsewhere (Champagne, Hoz, & Klopfer, 1984). Descriptions and some brief comments about the several probes follow.

Five probes of cognitive structure were used. Three of these have previously been used in psychometrically oriented studies of cognitive structure; the other two have been used previously in studies of students' conceptions of the motion of objects. The first three probes were group-administered, while the last two were administered individually. Cognitive structures derived from analyses of data collected with four of these probes describes a non-contextual structural organization of concepts. Although the structures obtained by these measures are in one sense contextual because the students are well aware that the content is science or physics, they are non-contextual in the sense that the concepts are not being applied to the solution of a specific task, for example, the comprehension of text or the

solution of a numerical or qualitative problem. An issue is the consistency of cognitive structures obtained in different contexts. That is, are the structures the same when the task is, say, to "arrange these terms as you think about them" as when the task is to analyze the motion of an object on an inclined plane. Thus, with the fifth probe, data on the structural organization of the target concepts in a specific context and students' application of the concepts were obtained by presenting the students with a physical situation, describing a manipulation to be performed, and asking them to make a prediction about the outcome of the manipulation and to describe the knowledge (facts and principles) that they used to make the prediction. Concepts the students did not use spontaneously were introduced by asking the students to evaluate predictions and explanations of the same situation given by other students.

Free Sort Task

The free sort task is a concept classification and categorization task that required students to categorize 17 physics concepts: acceleration, change of motion, direction, displacement, distance, force, frame of reference, inertia, mass, magnitude, motion, position, relative, resultant, speed, time, and velocity. No criteria for categorization were suggested. Various versions of free sort tasks have been used previously, (e.g., Gorodetsky & Hoz, 1985; Miller, 1969; Shavelson & Stanton, 1975), and Wiley (1967) proposed a multivariate scaling technique, latent partition analysis, for analyzing free sort task data. In our version of the task, student instructions began with an example of two ways in which 7 non-physics terms could reasonably be classified in order to emphasize the absence of a single, correct answer to the task. The instructions then reiterated the absence of a right answer, indicated that the words to be classified were on cards inside an envelope provided, asked that the words be classified into "categories that include words that you think belong together," and pointed out that any number of categories was possible and that any category could contain any number of words. On completion of the card categorizing, students transferred their grouping to an answer sheet containing 12 boxes. No time limit was applied to the task.

Tree Construction Task

In the tree construction task, the students were asked to construct a linear undirected graph (tree) of the same 17 physics concepts used in the free sort task. This type of task was devised by Rapoport (1967; Fillenbaum & Rapoport, 1971) as a method of measuring semantic distance between con-

cepts. Hierarchical clustering (S. C. Johnson, 1967) is the scaling method that has been most commonly employed in the analysis of Tree Construction Task data. In our version of the task, the students were given an alphabetical list of the 17 concepts and were instructed to "pick the two words from the list which you think are *most related* to each other," write the words in the center of the page, and connect them with a line numbered "1." This was then built on by adding another word from the list which was seen as "most related" to one of the two already used, then connecting with a line numbered "2." Either this procedure continued or a new tree was started, depending on the student's judgment of the extent of relatedness. Instructions required students to eventually join up trees if they had produced more than one so that the total response to the task comprised the 17 words and 16 numbered connections. Again, no time limit was applied.

Word Association Task

The word association task gave the student a one-minute time period to generate as many free associations as possible when each of these 5 concepts was successfully used as a stimulus: force, mass, speed, inertia, change of motion. This type of task derives from work on the determination of the associative meaning of concepts (e.g., Deese, 1965), and it has been used in several studies concerned with the cognitive structures of physics students (e.g., P. E. Johnson, 1965; Preece, 1976; Shavelson, 1972). In our word association task, when the students had completed each set of associations to a stimulus, they were asked to compose a sentence for each individual association which contains both the stimulus word and the associated word. The sentence-composing procedure, previously used by Gunstone (1981), is intended to elicit information about the nature of the associative link, and this part of the task is given without a time limit.

Concept Structuring Analysis Technique

The concept structuring analysis technique (ConSAT) task used the same 17 concepts that appeared in the free sort and tree construction tasks. The ConSAT was devised by Champagne and Klopfer as a way of eliciting graphic representations of students' cognitive structure (Champagne, Klopfer, De Sena, & Squires, 1981). For our student interviews using the ConSAT, the concepts were written on small cards, and the student was asked to identify which ones he or she recognized, and then to provide a definition for the recognized concepts. Finally, the student was asked to arrange the recognized concepts on a sheet of paper "in a way that represents how you think about the words and about the relationship between them." When the ar-

rangement was completed, the grouped concepts were circled and the student was asked why he or she made this arrangement and to explain particular groupings. The student's answers were tape-recorded and written on the sheet containing the arrangement.

DOE Interview

For this probe of the student's cognitive structure, the demonstrate, observe, explain (DOE) task, described in the review of our earlier research (see Chapter 5, this volume) was modified for use in an individual interview context and to elicit more extensive responses from the student. For a sequence of physical demonstrations, the student was asked to give a prediction of the outcome of the demonstration, to explain the basis of the prediction (knowledge used, relevant personal experience, etc.), to observe the demonstration, and to consider any differences between prediction and observation. In addition, prior to observing the demonstration, the student considered a set of predictions and explanations given on previous occasions by other students and was asked to describe the way in which various concepts were being used in these students' answers and to compare them with his or her own ideas. The entire interview was tape-recorded.

Pre- and Post-Tests

Identical task forms were used before and after the instructional period with the exception of the DOE interview. On the pre-test, the DOE interview involved a sequence of demonstrations based on a dime placed on a piece of cardboard that in turn could move along a suspended, sloping meter rule. On the post-test, the demonstrations were based on a dime placed on a block of wood which was in turn placed on an inclined plane. That is, the demonstrations in the two DOE interviews had different surface features and the same deep structure.

The Pittsburgh Group

The instructional group was comprised of 13 middle school students selected from school districts in Allegheny County. These students were all designated as academically gifted by the criteria set forth by the Pennsylvania Department of Education and all had demonstrated an interest in science out of school. A control group of 10 was selected from the same school districts by use of the same criteria. This group was also given the cognitive structure probes on two occasions separated by eight weeks, but did not experience any special program in this time.

The instructional period occupied 10 weeks, during which the students came to the Learning Research and Development Center at the University of Pittsburgh for one full day, from 9:00 A.M. to 2:30 P.M., each week. The first session was occupied primarily with an orientation to the program, organizational matters, and the pre-instructional student assessment. Most of the tenth session was devoted to presentations given by the students for their parents and regular science teachers. The post-instructional testing took place near the end of the ninth session. Hence, with allowances for breaks and lunch, the total instructional time available was approximately 30 hours. In each day's session, generally about 2 hours and sometimes more were spent in discussions of students' ideas and various issues concerning motion. These were the occasions when the ideational confrontation strategy was most directly applied. The rest of the time in each session saw the students engaged in carrying out various laboratory activities involving inclined planes, force tables, an air track, and other apparatus, or in performing computer-simulated mechanics experiments, or both. While the students worked on these activities in small groups, an instructor was generally at each station to raise questions and promote further discussions.

For the instructed group students as a whole, their previous formal instruction related to the physics of motion was minimal. The 6 eighth graders in the group had been exposed prior to the beginning of this study to the 3- to 4-week unit on motion, energy, and machines typically found in eighth-grade physical science or general science textbooks. The group's 6 seventh graders and 1 sixth grader had not received even that much formal instruction relating to mechanics prior to this study. Their in-school exposure to mechanics was limited to whatever may have been included in their elementary school science programs, few of which include very much. Two of the students reported that they had studied topics in mechanics quite extensively on their own.

FINDINGS FROM THE COGNITIVE STRUCTURE PROBES

In the tree construction task, the students were asked to select the pair of concepts they considered most related, the second-most-related pair and so on. We found that their choices for the early positions focused on a very limited number of the concept pairs. Of the 136 possible pairs, only 9 different pairs were cited on the pre-test as most related by one or more students, and only 7 different pairs were selected first on the post-test. All told, only 30 different pairs were selected first, second, or third by any student on the pre- and post-tests combined. Seven of these 30 pairs accounted for 54% of all the selections for the first three positions.

On the pre-test, the pairs most frequently selected as the most-related concepts were speed–velocity (three times) and motion–speed (three times). Solitary selection of most-related concepts went to each of these seven pairs: motion–change of motion, direction–distance, acceleration–velocity, inertia–speed, acceleration–speed, time–speed, mass–displacement. When the students repeated the tree construction task on the post-test, they again picked the speed–velocity pair most frequently (four times) as the most-related concepts, but now the force–motion pair was selected as the most related by three students and the acceleration–change of motion pair was selected for first position by two students. Pairs each selected once on the post-test as most-related were acceleration–force, distance–displacement, direction–distance, and magnitude–velocity. It is of interest to note that the most frequently selected first position pair on both the pre- and post-tests is one where the concepts (speed and velocity) are viewed as synonyms by the students. Also noteworthy is the observation that the concept of *force* does not figure in any of the most-related pairs at pre-test time, whereas it appears four times in first position pairs on the post-test. This change is consistent with one emphasis of the intervening instruction.

In the instructed group's responses to the word association task, the total number of associations made by the 13 students on the pre-test was essentially the same as on the post-test (290 vs. 292). However, the associations they made were very different. A total of 137 terms was used to generate the pre-test associations. After instruction, 179 terms were used to generate the associations. About 42% of the terms used on the pre-test were also used on the post-test. However, an analysis of the sentences generated using these repeated terms shows that, with a few notable exceptions, the relationship between the stimulus and the associated term changed from pre- to post-test.

Two instances where the relationship between the stimulus and associated term did not change were between force and motion (movement) and between mass and weight. In both instances, the maintained relationship was a scientifically incorrect one. Nonetheless, in most cases, the sentences containing both terms were not propositions directly relating to the concepts (e.g., "*mass* is not the same as *weight*"; "*force* is a *vector* quantity"), but rather sentences in which the two terms happened to co-exist (e.g., "The *force* of the *power* plant is unmanageable"). Most of the sentences were contextual (e.g., "I am *exerting* a *force* on this chair") and in no instance were concepts related in a formal way (e.g., "*Force* equals *mass* times *acceleration*"). In summary, two observations relevant to the relationships between terms are that there is little consistency between pre- and post-test associations and that there is no identifiable trend in the changes from pre- to post-test.

Before producing a concept map in the ConSAT Task, the students were asked to identify which of the 17 concepts they recognized and which they did not. On the pre-test, five different concepts were placed in the unrecognized pile by one or more students. The concepts identified as unrecognized were frame of reference (five times), resultant (four times), displacement (two times), velocity (one time), and relative (one time). Moreover, no definitions of any kind were recorded by 11 students for frame of reference, by 10 students for resultant, by 7 students for displacement, and by 2 students for relative. On the post-test, none of the 17 concepts was classified as unrecognized. Definitions were not given by 2 students for frame of reference and by 1 student for displacement.

The difference in knowledge of the concepts is also indicated by the pre- and post test difference in the terms for which the students gave definitions. On the pre-test, there were 38 places, involving 10 different concepts, where a definition was not even attempted. On the post-test, there were only 9 occasions, involving 6 concepts, where students did not give a definition. Approximately 75% of the 38 omitted definitions at pre-test were for the three concepts frame of reference, resultant, and displacement. At post-test, all of the terms were predominantly defined in a way which was consistent with a physical science definition, as opposed to merely an instance of the concept describing or providing an example which involves the concept. Also, at post-test the definitions incorporated markedly more physical science concepts from the list of 17 concepts itself. Changes also occurred in the structural organization of the terms. These changes point toward the development of increased concept differentiation. Both the pre- and post-ConSAT structures contain groups of terms. Each group has a superordinate term characterizing the terms in it and each of the groups is typically linked to another group by a relationship. Expert structures of the same terms do not have any groups—each term being linked to another by a specific relationship. We take this as evidence that the terms are not well differentiated by the students. Evidence that the students are beginning to differentiate the terms better is provided by the fact that in the post-instructional structures there are on average more groups and more explicit relations between individual terms within groups. This is in contrast with global statements about relationships between associated groups of terms that are evident in pre-instructional structures.

In the transcripts of the DOE interviews given before the instruction, the most striking feature of the students' analysis of the inclined plane is the absence of any of the target terms in the reasons the students give for their predictions. The students' analyses of the physical situation were consistently based on two surface features of the situation, the slope (angle of incline) of the plane, and the roughness of the surface on which the coin was

placed. A few students mentioned friction and gravity as factors related to roughness and incline but no student attempted any analysis of the forces on the coin. On the post-test DOE interview, even though the students had been exposed to very specific instruction about the gravitational and frictional forces on objects in free fall, none of them applied anything resembling a force analysis to the coin on the block in the post-test problem. All used an argument based on surface features similar to that used on the pretest. Even though the information and skills necessary to attempt a force analysis were available to the students, the real-world nature of the problem triggered the well-practiced analysis.

THE VICTORIAN GROUP

The students involved in the Victorian part of the study were science graduates undertaking a one-year course in teacher training at Monash University with the aim of teaching high school biology or chemistry. In the Victorian context this means that they would also teach general or integrated science in years 7–10 of high school, and thus be involved in teaching physics concepts. As all of our work on instruction to change physics cognitive structures prior to this study had been with middle school students, a pilot program was run with eight trainee teachers. None of the data from this trial is reported here.

Because of course and administrative constraints, the group involved in the study were all volunteers. The choice to join the group was made on the basis of information describing what would take place as being "Physics for Non-physicists" directed toward developing an understanding of important ideas in elementary physics. Students had the option of joining this group or one of thirty or so others which ran across the total spectrum of issues of possible relevance to trainee teachers.

The group comprised six students. It is clear, given the circumstances described above, that all six both saw their understanding of physics to be inadequate and had considerable motivation to try to rectify this situation. The group met for two full days each week, from 9:30 A.M. to 4:00 P.M. The first day of the first and fourth weeks was given over to the group and individual tests of cognitive structure. Thus, the instruction occupied five days, or about 30 hours. A control group was generated, again by calling for volunteers. However, the resulting group differed considerably from the instructed group in terms of physics background, and consequently, the control group data are not considered here. This problem emphasizes that the instructed group cannot be considered a representative sample of the population of prospective secondary science teachers who have inadequate training in physics.

Because of the nature of the group, there were some differences in the conduct of the study by comparison with Pittsburgh. The Victorian students reacted individually (in writing) to the experiences of each day and to the whole sequence. In addition, on the first day they gave relevant biographical data and their perceptions of the areas of physics they believed they understood or did not understand. Discussions with the group tended to run for longer periods of time and cover a wider variety of relevant issues than was the case with the Pittsburgh group.

The same five cognitive structure probes were used in pre- and post-instruction. Thus far, the analyses of these data have been somewhat different from the Pittsburgh analyses, being more global, having a stronger focus on the individual probes than on the group probes, and including inspection of the transcripts of the instruction sessions. The major reasons for this approach being the first consideration of the data are the very different pre-instruction cognitive structures of the group (as compared with the Pittsburgh group) and the clear indications through the period of the study of changes in the ways individuals interpreted physics-based events and issues (and, therefore, the implication that cognitive structures had been changed).

Findings and Discussion

All six students had undertaken physics at Years 11 and 12 in high school (the normal mode of school physics study in Victoria), and four had completed first year university physics. All were biology or chemistry majors. Four claimed to understand basic mechanics when given open-ended questions about their knowledge of areas of physics at the first sessions, one stated he did not understand vectors and another that he did not understand mechanics but did understand forces. Given the extent of physics courses undertaken, it would be expected that the students would have some knowledge of school physics. Within limitations this was the case. Where individuals are identified in the discussion, C, I, J. L, N, and Z are used.

Data from the word association task did not show the characteristics evident in the Pittsburgh data. At the analysis-by-inspection level used thus far, much more consistency is evident. Just over 50% of pre-test associations were repeated in the same sense (as judged by the sentence produced for each response) on the post-test. A significant number of non-repeated responses were synonyms and examples (e.g., in response to *change of motion—stop, start, slow down, veer;* to *force—gravitational, electric, magnetic, nuclear*). Although the pre-test produced a considerable number of propositions, there were relatively few relationships. Associations reflecting $F = ma$ were given by all, but the accompanying propositions indicated a lack of precision in the view of this relationship. The above comments do not

apply to J whose associations were more precise and reflected something nearer to a physicist's view.

In every case but one (student I), the first chosen pair of concepts in the tree construction task were descriptive and kinematic (e.g., speed–velocity, displacement–distance). Student I began with force-resultant. This observation bears striking similarity to the pairs selected by the younger Pittsburgh sample, which were overwhelmingly descriptive and kinematic. This observation is interesting in terms of the view expressed by Easley (1971; quoted at the beginning of the paper). In the free sort task there was a tendency for groupings to be formula-based.

The request for definitions which is part of the ConSAT Task caused difficulty for all students. While all students sorted all concepts into the "recognized" pile, except for N who had two "unrecognized" (frame of reference, inertia), there was universal unease about the request for definitions. Although demonstrably incorrect definitions were rare, attempts which were sufficiently vague as to be inadequate were relatively common. Even vagueness was not always reached for more abstract concepts such as inertia. The subsequent concept maps, in most cases, reflected these problems. Inertia was most commonly placed on the map with considerable difficulty. Links beyond the initial joining of two concepts were rare. As for the word association task, student J was an exception. Her concept map was more integrated and her definitions both more precise and more confidently advanced.

All students gave predictions consistent with subsequent observations for situations in the DOE interview. However only one (student J) consistently used a force analysis in explaining this series of statics and dynamics situations. The other five, to varying degrees, explained in terms of the surface features of the demonstration rather than the underlying physics. Both these explanations and the reactions to the set of provided answers produced a number of incorrect statements about forces and motion.

In general, with the exception of J, the pre-instruction cognitive structures of the students were characterized by the presence of relationships in the form of formulas which were not utilized for real events or other applications and by the presence of considerable propositional knowledge which lacked specificity and was occasionally incorrect. A very brief summary of these features emerged at the beginning of the first instructional session. The first task in this session was to consider the question, "What are some of the things we can say about the relationships between force and motion?" Students recorded consensus answers on a blackboard. A facsimile of that blackboard is given in Figure 11.1. This blackboard summary remained throughout the period of instruction, with modifications being made as students saw these to be necessary. It is interesting to note that an early

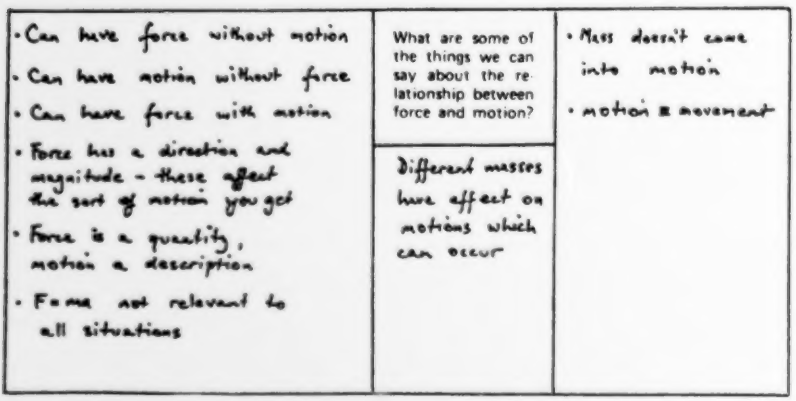
• Can have force without motion
• Can have motion without force
• Can have force with motion
• Force has a direction and magnitude - these affect the sort of motion you get
• Force is a quantity, motion a description
• Forces not relevant to all situations
What are some of the things we can say about the relationship between force and motion?
Different masses have effect on motions which can occur
• Mass doesn't come into motion
• motion = movement

FIGURE 11.1 Blackboard summary after first segment of first instructional segment.

response given to the beginning question in the first session was "$F = ma$." All agreed this was an appropriate answer but, when then asked to explain what it meant, no student was prepared to volunteer an answer.

In their reactions to what was happening written after each instructional session, all students made claims which suggest that changes were occurring in their cognitive structures. Their reactions are summarized before the post-instruction probes are discussed.

After the first session, all wrote in terms of "I don't understand what I thought I did," and all indicated a positive motivation to the experience. This positive reaction was apparently contributed to by a long discussion about normal reaction forces. During this discussion (as shown by the transcript), considerable steps were taken toward reconciling an intuitive view of force being a dynamic entity associated with movement with existing knowledge from physics courses that a normal reaction force should be considered. In other words, as well as having their beliefs about their own understandings shaken, they also perceived that their understanding had increased in one area. The second session was largely devoted to prediction, observation, and discussion of falling bodies. (The actual instruction in this session is discussed more fully in the conclusion.) Student reactions after this session indicated considerable change in their views about physics learning:

> [The session] enabled me to see how others view things and why they view them this way. Made one think hard to get a totally convincing argument for your side and any inability to do this gives you the suspicion that you are not in fact correct in your initial explanations . . . helps in understanding our false misconceptions and being confident in our new ideas. (student N)

> During [the] group discussion I changed my mind about the forces operating on the falling bodies. . . . Some people fight hard not to change preconceived ideas. (student I)
>
> It feels strange to contradict oneself half an hour later. It's worth the lengthy time involved because I can have time to gradually understand the issue at point. . . . [It's] as if we are trying to turn a blind eye to the truth. It's comforting to try to keep certain ideas forever even if there's a chance that they may be wrong. (student Z)
>
> I'm shattered! Didn't realize how devastating it could be to have a deep rooted belief proved wrong. Can I blame my physics teacher? It would be all right if some dummy didn't pose a question which could be used to support the opposite argument. Seriously though, very instructive. I don't know if I'm going to be able to last the distance. I'm mentally exhausted after each session and the effort to hold out when I'm wrong is very draining. Great fun so far even if I hate it at odd times. (student C)
>
> Even though I had the correct idea today that acceleration is approximately constant, at first I could only say that the forces were different by using $F = ma$. After having to think of arguments for this, I could justify it from an observational point of view. . . . The open discussion and justification of ideas is a brilliant way toward understanding physics. Substituting numbers in formulas seems to be a poor alternative. (student L)

Student J, whose pre-instruction data suggested a more comprehensive relevant cognitive structure, gave physically appropriate predictions and explanations for all situations used in Session 2. However, even she reported that "my *very first* impulse was to claim that equal forces were acting on the balls [of different mass]."

The general trend evident in the above quotes continued through the remaining session, although the reactions were not elaborated in such detail. For example, student C commented, "I don't smart so much any more" (after Session 4) and, "Becoming more receptive to change in my supposed convictions" (after Session 5). The written reactions to the whole sequence of instruction were also very consistent with the above quotes from Session 2 reactions. Students all expressed the belief that their views had changed (with all giving detail of at least some of these changes). The importance of discussion, of considering the views of others, or relating a situation under consideration to other real-world phenomena were all seen to be significant in promoting changes of view.

The blackboard summary at the end of the instruction is represented in Figure 11.2. The progressive changes evident in this figure had been made in response to the question, "Is there anything you would like to change on the blackboard?" at the end of Sessions 2, 4, and 5. Students were not specifically asked to add additional statements, only to consider modifying what was there. This final summary shows less imprecision and more correctness (in terms of the physicist's view of force and motion).

The post-instruction probes of cognitive structure suggest that the cog-

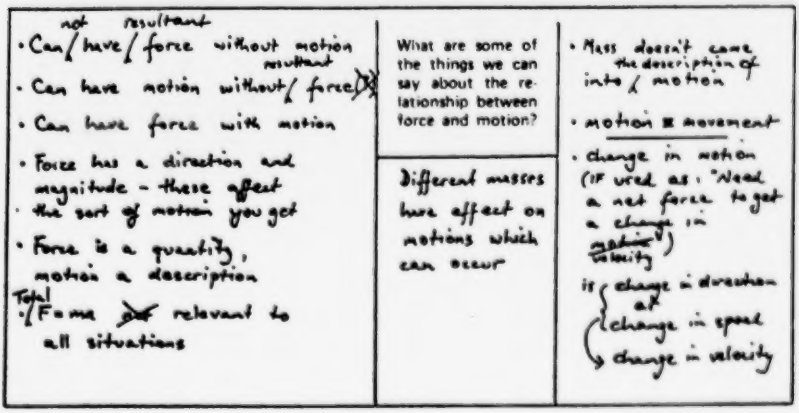
• Can (not resultant) have force without motion
• Can have motion without (resultant) force
• Can have force with motion
• Force has a direction and magnitude - these affect the sort of motion you get
• Force is a quantity, motion a description
• (Total) F=ma not relevant to all situations
What are some of the things we can say about the relationship between force and motion?
Different masses have effect on motions which can occur
• Mass doesn't come into the description of motion
• motion ≠ movement
• change in motion (IF used as: "Need a net force to get a change in motion/velocity")
is (change in direction or change in speed) = change in velocity

FIGURE 11.2 Blackboard summary after completion of instruction.

nitive structures of four of the students have been changed in the ways they reported through the instruction. The exceptions are student J (who, in simple terms, had less to change in her cognitive structure), and student N.

The most powerful, even though general, evidence of a change in cognitive structure comes from the DOE interview. All students except N immediately described the situation used as being the same as that used in the pre-test despite the two situations having quite different surface features. All but N consistently used the underlying physics principles to explain their predictions and their evaluations of the provided set of answers. Student N showed some tendency to do this, but was not consistent. Only student N used imprecise statements in responding to the situations.

The definition task involved in the ConSAT Task was much more positively approached and much more appropriately answered. Impression was evident in mass and inertia definitions from student N and inertia from student C. By comparison with the pre-test maps, concept maps showed more connections and greater precision in connections.

In the tree construction task, the most related pair of concepts was seen to be *mass* and *inertia* by students I, J, and L. The remaining three selected a pair of descriptive, kinematics terms as they had done on the pre-test, although no student began with the same pair as they had on the pre-test. The word association data showed a decrease, relative to the pre-test, in synonym and example responses for all students. However, the total associations given increased by 29%, and by about 40% for the abstract concepts *force*, *mass*, and *inertia*. Increases were much smaller for the more familiar

descriptive terms speed and change of motion. Incorrect propositions on this task were very infrequent and there was much more precision evident. Relationships between concepts were more frequent than on the pre-test.

FURTHER PITTSBURGH ANALYSES

In addition to examination by inspection of data collected from the instructed group, a number of statistical analyses which apply various scaling techniques to the response data obtained via the several probes of cognitive structure have been undertaken.[1] The data from the three group-administered probes (word association, free sort, and tree construction tasks) have been analyzed. Proximity matrices have been produced from responses to each of the three tests and scaling methods applied to these matrices to produce representatives of cognitive structure. Latent partition analysis (LPA), multi-dimensional scaling (MDS), and hierarchical clustering (HC) methods were applied to the proximity matrices from each of the three tests, with the exception of the word association matrix to which LPA cannot be applied. Hence eight representations of group cognitive structure resulted. The procedures adopted for analysis of responses to each of the three tasks is described elsewhere (Champagne et al., 1984). A brief discussion of the results of the quantitative analysis follows.

Analysis of the Pittsburgh data from the word association task yielded relatedness coefficients for pre- and post-test data from the same group that are generally low and sometimes zero. This finding led us to conclude that these input data were too unreliable to permit valid statistical analyses. Hence no further analyses are reported.

The previous finding is difficult to interpret. Both in a previous study in which an identical word association task was used in a pre- and post-instruction context (Gunstone, 1980) and in the Victorian section of this study quite contrary observations have been made. Because these latter uses involved Grade 11 and teacher-training students respectively, the age of the Pittsburgh students might provide an explanation. It is logically reasonable to suggest that the Pittsburgh word association observations result from students of this age having cognitive structures in this content area which are, relative to older students, poorly articulated and unstable in terms of propositional knowledge. However, no support for this hypothesis exists beyond the general perspectives we have formed from working in this content area with middle-school students.

The other analyses conducted suggest little change in the cognitive structure representations derived for the Pittsburgh students. For every com-

[1]These analyses were developed primarily by our colleague, Ron Hoz, who also guided the data reduction, scaling, and interpretation work.

bination of the two remaining data-gathering tasks (free sort, tree construction) and three scaling methods (LPA, HC, MDS) used: (1) the cognitive structure representations of the instructed and control groups derived from the pre-test are quite similar, and (2) the cognitive structure representations of the control group derived from the pre- and post-tests are quite similar. The degree of similarity in these two comparisons serves as a baseline for assessing possible pre-post- changes between pre- and post-test in the cognitive structure representations of the instructed group students. We find that the instructed group's post-test representations are just as similar to their pre-test representations as the representations compared in comparisons (1) and (2) are. Hence, changes are not evident in the instructed group students' cognitive structure representations from pre- to post-test. Using the same baseline, we also observe that, consistent with the preceding findings, the cognitive structure representations of the instructed and control groups derived from the post-test are quite similar. Only one set of representations is presented here, as this set is typical of the consistency evident in all representations. Figures 11.3–11.6 show two-dimensional con-

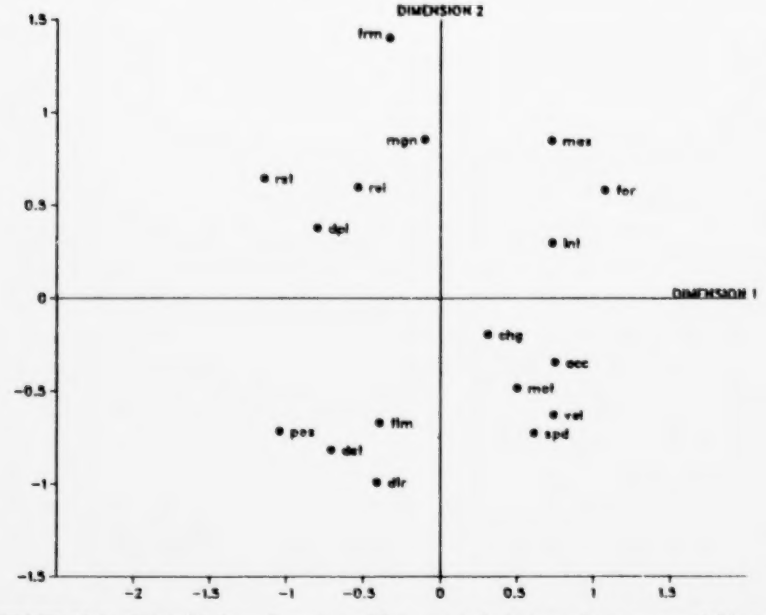

FIGURE 11.3 Rotated 2-D configuration of free sort task, instructed group, pre. (Abbreviations used: acc, acceleration; chg, change of motion; dir, direction; dpl, displacement; dst, distance; for, force; frm, frame of reference; int, inertia; mas, mass; mgn, magnitude; mot, motion; pos, position; rel, relative; rst, resultant; spd, speed; tim, time; vel, velocity.)

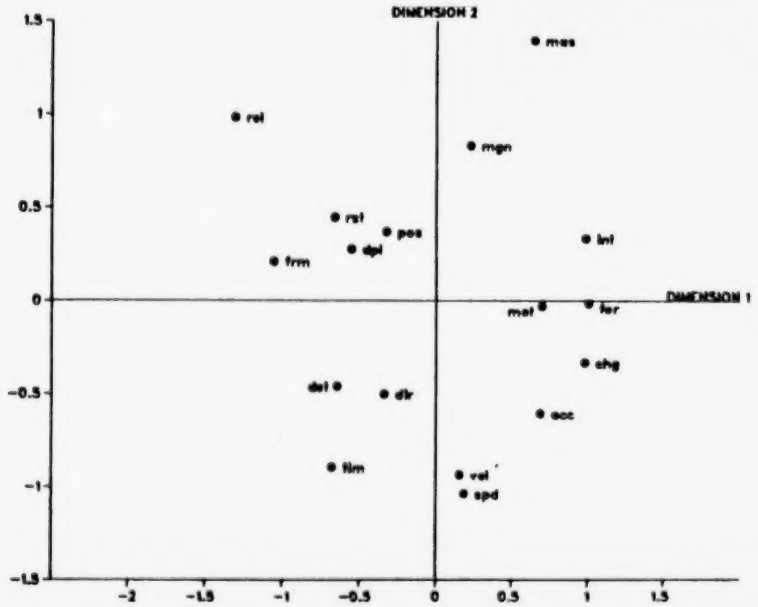

FIGURE 11.4 Rotated 2-D configuration of free sort task, instructed group, Post. (Abbreviations explained on Figure 11.3.)

figurations derived from the free sort task data for instructed group pre- and post-test and control group pre- and post-test, respectively. These representations depict the 17 concepts located in a two-dimensional space, which was chosen as the optimal solution in the application of multidimensional scaling. Both visual comparisons and calculated indices of goodness of fit for each pair of representations suggest considerable stability in the cognitive structure representations of the instructed group.

This apparent failure of the instruction to produce detectable changes in cognitive structure has a number of possible interpretations, three of which we advance here.

1. Our previous work points to the difficulty of changing cognitive structures associated with the interpretations of events which are part of the students' real world. In the area of introductory mechanics considered in this study in particular, there are grounds for arguing that pre-instruction conceptions derived from experience are more resilient than are conceptions in other science areas.

2. The possible explanations for the unexpected characteristics of the Word Association Task data presented above may be relevant here. That is,

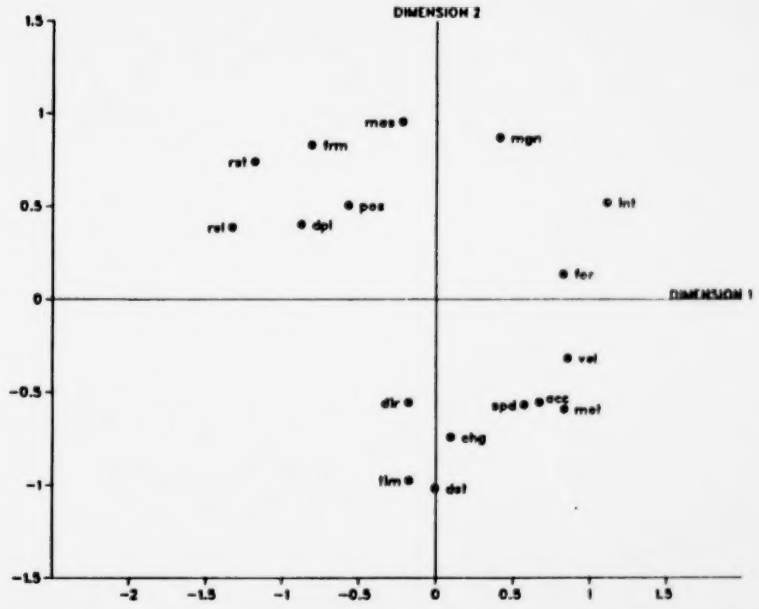

FIGURE 11.5 Rotated 2-D configuration of free sort task, control group, Pre. (Abbreviations explained in Figure 11.3.)

the failure to detect change in these cognitive structure representations may be a result of students of this age having cognitive structures in this content area which are not well articulated and are frequently unstable in terms of propositional knowledge. Given this, one could argue that the stability in representations may result from the nature of the task, and might not be found in other data.

3. Although no change was detected, there were differences in the instructed group pre- and post-test responses to the cognitive structure probes. For example in the Free Sort Task, differences are observable both by inspection and by the correlations of the proximity matrices derived from the pre- and post-test responses of both groups. The correlations may indicate changes in the instructed group cognitive structure that were not detected by the target terms and analytical methods applied.

The target terms were selected to represent the major concepts related to classical mechanics and to detect any major restructuring of the students' conception of mechanics from some naive perspective to the Galileo-Newtonian one. A significant finding of the quantitative analysis is the similarity of cognitive structures of the instructed and control groups, both before and

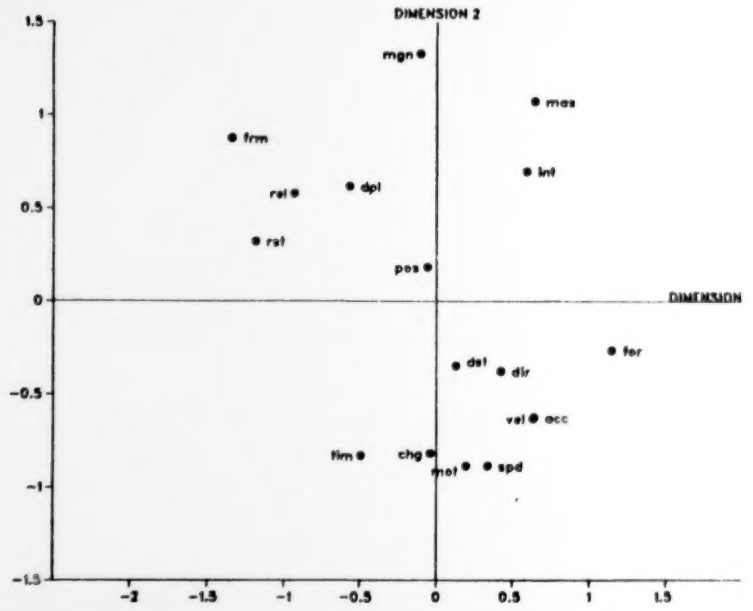

FIGURE 11.6 Rotated 2-D configuration of free sort task, control group, Post. (Abbreviations explained in Figure 11.3.)

after the instructional treatment of the instructed group. This finding lends support to the qualitative studies done by many investigators which have revealed the consistently Aristotelian characteristics of the naive conceptions of mechanics of a broad range of students. These results also substantiate the reports by other investigators that the Aristotelian features of beginning students' conceptions are difficult to change.

Clearly no major restructuring of the Pittsburgh students' conceptions occurred as the result of the instruction. However, there is evidence that students' knowledge about certain target terms (e.g., frame of reference) did increase and that this knowledge made the students' analysis of the motion of objects more powerful. Some important changes also occurred in students' differentiation of terms; for example, their awareness that there is a significant difference between mass and weight. These comments about changes in instructed students' knowledge are consistent with findings in the quantitative analysis of the data (Champagne et al., 1984). Moderate differences between proximity matrices derived from task response data are washed out by the analytical methods used to produce the cognitive structure representations.

CONCLUSION

The purpose of this research was to investigate the effectiveness of the ideational confrontation strategy in producing conceptual change. Conceptual change can be effected in either the contents of cognitive structure or their structural organization. Findings from this preliminary study suggest that the ideational confrontation strategy has promise both for engendering restructuring of students' existing knowledge and for changing the contents of their knowledge. Moreover, the strategy produces other significant changes, for which we saw evidence in the complementary findings for the two groups.

A general observation from the findings is that the effects of the ideational confrontation strategy differ somewhat for students with different characteristics. Perhaps this interaction was most clearly demonstrated with respect to the changes in knowledge structure and contents, but it applies to the other aspects of change as well. An obvious difference between the students in our two groups is that the Victorian students had more verbal knowledge derived from formal physics at the outset than the Pittsburgh students. The contents of the Victorian students' knowledge before the instruction included quite a reasonable share of propositions based on the Galileo–Newtonian view of mechanics (even though their interpretations of real phenomena were often not Newtonian). By contrast, the knowledge about motion held by the Pittsburgh students, who as a group had previously had very little mechanics-related instruction, was essentially limited to their naive, Aristotle-like, experience-based conceptions pertaining to the motion of objects. In the course of instruction utilizing the ideational confrontation strategy, the Victorian students were able both to place a new structure and to better reconcile this formal knowledge with interpretations of real-world phenomena. For the Pittsburgh students, the main effects of the strategy on their knowledge were to increase its precision through the differentiation of related terms, to augment the contents with some new mechanics concepts (e.g., resultant) and to inject the physicist's canonical meanings of certain concepts (e.g., acceleration, force). All these effects can contribute to the formulation of explicit propositions about motion and to the nascent structuring of propositions, but they do not indicate a restructuring of the student's larger conceptual structures related to the motion of objects. In other words, the effects of ideational confrontation on the Pittsburgh students' knowledge differs from those for the Victorian students, but they are also consistent with the differences in initial knowledge.

Another general area where the strategy produced complementary effects for the two groups concerns the students' construction of valid and convincing explanations for observable physical phenomena. It is remarkable that the students in both groups were initially quite reluctant to construct such

explanations, as we saw in the pre-instructional DOE interviews and the initial days' discussions. For the Victorian group, the change from reluctance about explaining motion phenomena to persistence in seeking the best explanation took place more rapidly than for the Pittsburgh group and was closely related to the developing awareness of their own thought processes and the nature of their knowledge. Inspection of the transcripts of the Victorian instruction sessions and the students' reactions to the sessions does not suggest a dramatic "flash of inspiration" when this change was suddenly made, but rather that the students' self-awareness developed over a period of time. However, it is clear that the ideational confrontation in the second session was of great significance. In this session, students began by predicting the relative times of fall for 2 spheres of about 0.1 m diameter when dropped from about 2 meters. One sphere was lead, the other a plastic ball. Although all predicted equal times, four (C, I. N, Z) said this would be the case because the same force acted on each sphere. This difference was debated at length. The process was then repeated for the spheres dropped from a height of about 12 meters (for which there is unquestioned difference in the time of fall), for two cubes of identical volume and different mass dropped about 0.25 meter in water, and finally for the two cubes dropped the same distance in oil. This process occupied about 5½ hours (with coffee and lunch breaks not included). Transcripts and students' reactions make it clear that the first part of the next session—discussion of a demonstration of two carts of different mass being pulled by identical forces at the same time—should be seen as part of this sequence.

The significance of this sequence lies not in the changes in specific knowledge contents per se, but in the way in which this experience promoted strongly held alternative views and lengthy and voluble debate. This particular sequence resulted in all students indicating that they began to understand the origin and resilience of views which caused them to be conceptually troubled by the perspectives advanced in their previous physics courses. It was common through the remainder of the instruction for individuals to overtly use the second session experience to argue to themselves and others about internal consistencies in their interpretations of events and inconsistencies between these interpretations and the tenets of Galileo–Newtonian mechanics. Having developed this degree of introspection, the Victorian students became quite adept in seeking out reasonable explanations for motion phenomena and, in doing so, they were prepared to continue debate on an issue for extreme lengths of time.

The Victorian students' far greater maturity and cognitive development allowed them to become more introspective than the younger Pittsburgh students. Nevertheless, at their own level of development, the Pittsburgh students also learned to devise explanations for motion phenomena through

the process of constructing arguments. In fact, the ideational confrontation strategy requires that students become skillful in developing arguments to support their assertions and to defend a point of view in the face of conflicting opinions. Students must also be motivated to exercise these skills. A major change in the behavior of the students in the Pittsburgh group was the development of the ability and the willingness to engage in discussions about the motion of objects.

Once the students became convinced that this behavior was acceptable—even desirable—the group debated scientific issues at length and with enthusiasm. Our preliminary analyses of transcripts of the instruction suggest that the quality of the students' arguments improved over the course of the instruction. At about the mid-point of the Pittsburgh instruction, a visitor observed a lengthy discussion about the weight of a brick in water, and he expressed both surprise and delight about the length and quality of the discussion. Comments made by two of the students' teachers who also observed the discussion are also significant. One teacher noted that much valuable time would have been saved if the students had simply been told the answer. Another teacher wondered if the science classroom is an appropriate place for discussion. Given the prevailing attitude of teachers, the observed initial reluctance of the students to engage in discussion that lead to reasoned explanations is not surprising. However, the important observation is that this reluctance can be overcome via the use of such strategies as ideational confrontation.

One problem noted with regard to this strategy was the large difference in participation in the discussions by the Pittsburgh young women and men. With one exception, there was significantly less participation in the discussion by the young women, and efforts by the female instructor to actively encourage their participation were not successful. At this time, we have no satisfactory suggestions for alleviating this problem, which probably has its roots in prevailing societal attitudes and in the developmental process of adolescents. The problem of differential participation in discussions by gender was not strongly manifested in the Victorian group of much older university students, all of whom were committed to becoming teachers, whose social role is generally perceived as expressive.

In summary, we have successfully used the ideational confrontation strategy to produce conceptual change in a content area for which we have found this process to be very difficult. We have achieved this change in what we regard to be the remarkably short time of approximately 30 instructional hours, spread over 5 days (Victoria) or 8 days (Pittsburgh). The changes in both groups involved the development of some understanding of the scientist's perspective concerning the physical domain of motion, an understanding which may well be applied by the students in other content areas.

Especially the Victorian students, with their greater introspective skills, were able to gain considerable insight into the distinction between the scientific way of knowing and knowledge based on individual experience and interpretation, and to use this insight to gain considerable understanding of the processes of their own learning. On completion of the course, all the Victorian students claimed that these personal metacognitive insights would influence their subsequent learning. This claim has not been investigated.

This research also has implications for the psychological theory underlying the ideational confrontation strategy. Ideational confrontation is one version of interactive dialogue, which has been proposed as a strategy to facilitate schema change (Anderson, 1977; Riegel, 1973). However, advocates of the strategy have not posited any theoretical mechanism by which the strategy produces cognitive changes. The results of the study reported here may inform the process of the development of such a theory. We propose that the active mental manipulation of concepts and principles in the formulation and revision of arguments plays an important role in the differentiation and integration of concepts and in the restructuring of knowledge. Equally significant is the strategy's influence on the development of the distinction between the scientific way of knowing and knowledge based on individual experience and interpretation. The process of engaging in interactive dialogue helps develop the ideas of rules of evidence and criteria for validity. This knowledge about the nature of science concepts and the procedures involved in establishing them may be a crucial link in the learner's formulation and reformulation of the contents of his or her own knowledge. This kind of mediating link may be developed in the course of engaging in interactive dialogue, such as ideational confrontation.

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